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Figures 1a to 1d show different embodiments of the invention in the form of block diagrams,

Figure 2 schematically illustrates a scanning microscope according to the invention,

Figure 3 illustrates an exemplary reference object, of the kind that can be used for the calibration mode of the microscope in Figure 2,

Figure 4 shows an exemplary signal S of the image acquisition device when the microscope in Figure 2, in the calibration mode, scans and acquires a reference object on a predetermined path 9 in accordance with the coordinate x at different times,

Figure 5 shows the exemplary correlation between the displacement of the line centroids, which is illustrated by the curve 15, and the temporally corresponding profile 14 of an interfering quantity which is detected outside the apparatus and causes the displacement of the line centroids,

Figures 6a to 6c show the displacement of the image centroid of three successive images,

Figure 7 shows the temporal profile 17 of the displacement of the centroid from Figure 6 for the x-direction, and

Figure 8 shows an exemplary embodiment of an optical microscope corresponding to the block diagram of Figure 1c.

Figures 1a-1d schematically illustrate exemplary embodiments of the imaging and/or raster-mode scanning apparatus 1 according to the invention in the form of scanning electron microscopes in block diagrams. The

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numeral 1 designates the apparatus without the compensation device for compensating for ambient influences which may degrade the imaging. The apparatus comprises a sensor 4 outside the apparatus, this sensor

4 outputting a first signal, which is dependent on the electromagnetic interference field at the location of the sensor, to a digital filter 5, the transfer characteristic of the filter 5 being set manually. The interference U affects both the sensor 5 and the apparatus 1, this being indicated, in this figure and also in Figures 1b to 1d, by the arrows proceeding from U. Having passed through the filter 5 and having been amplified in a regulating amplifier 6, connected downstream, the signal is applied to the electron beam deflection coils of the scanning electron microscope. The first signal which is dependent on the ambient influences and is applied to the signal input of the filter 5 can either be output by a sensor 4 for detecting at least one physical quantity outside the apparatus 1 (Figures 1a to 1c), or an output of the image processing device 2 is connected to the calibration input of the filter 5 (Figure 1d), with the result that the calibration signal depends on an image analysis, for example. The regulating amplifier 6 serves for matching the output signal of the filter 5 to the actuator and/or to the control element 3. In detail, then, a compensation signal, that is to say a signal which is dependent on the interfering quantity, that is to say the electromagnetic interference field, is applied to the actual driving signal of the deflection coils 3. The arrangement of the sensor 4 outside the apparatus should be understood, according to the invention, such that the sensor 4 is arranged in such a way that the driving of the actuator and/or of the control element 3 does not significantly influence the measurement signal of the sensor 4. The effect achieved by the calibration of the filter 5 is that the applied compensation signal for the image acquisition corresponds precisely to an opposite effect which is caused by the electromagnetic interference field at the location of the apparatus 1 and,

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consequently, the effect of the compensation signal application and the effect of the interfering electromagnetic field on the imaging essentially cancel each other out. If the scanning electron microscope 1 is moved to a different site, the filter 5 must be recalibrated in each case for the purpose of modelling the transfer function.

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Figure 1b shows a block diagram of an apparatus 1 according to the invention, in which the calibration of the filter 5 and thus the calibration of the apparatus 1 are carried out by means of a second signal from an image processing device 2 which is included in the image acquisition device 7 or is connected thereto.

Figure 2 corresponding to the block diagram of Figure 1b shows an apparatus of this type with the image processing device 2 being connected to the calibration input of the filter 5 in the case of a scanning electron microscope. The image acquisition device 7 acquires at least one pixel of the object and supplies the image processing device 2. As in the case of the first embodiment, the signal of the sensor is fed forwards to the deflection coils 3a, 3b. A signal for driving the calibration input of the filter 5 is generated in the image processing device 2. The calibration of the filter 5 and thus of the apparatus 1 is described below with reference to two different embodiments.

According to a first embodiment, the microscope 1 is set up for operation in a calibration mode and an image mode, whereby, in the calibration mode, ambient influences that reduce the imaging quality can be detected by the imaging of a predetermined reference object and comparison of the image with the real structure of the reference object, and can be essentially eliminated by calibration of the microscope 1, and the imaging defects are greatly reduced or essentially compensated for, even in the event of a change in the ambient influences, by maintaining the calibration in the image mode. Depending on the operating mode, the input signal of the calibration input of the filter 5 either depends on the respective measured imaging defect (calibration mode) or is obtained by means of the data stored during the

calibration mode (image mode). It is possible to switch back and forth between the calibration and image modes.

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The calibration mode is utilized in order to detect ambient influences, that is to say in this case the electromagnetic interference field which reduces the imaging quality, by the imaging of a predetermined section of a reference object and comparison of the image with the real structure of the reference object, and to calibrate the apparatus in such a way that systematic imaging defects caused by external ambient conditions and/or caused by instrumentation are essentially compensated for. According to the invention, this calibration of the microscope 1 is carried out by setting the transfer characteristic of the filter 5. Figure 3 illustrates how the scanning device scans a selected section of a reference object in the calibration mode, in which case, in the digital image processing device 2, a stored signal assigned to the reference object is compared with the image signal of the reference object that is obtained from the image acquisition device 7, and a signal assigned to the difference is formed and is output to the calibration input of the filter 5.

The calibration method in the calibration mode can be described by the following steps:

- determination of a first signal, which depends on the electromagnetic interference field at the location of the sensor, by a sensor 4;
- application of the first signal to the signal input of the filter 5;
- acquisition of a selected section of a predetermined reference object by means of an image acquisition device 7 by scanning the reference object;
- comparison of the acquired image with the real structure of the reference object;

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- determination of a defect signal assigned to the difference;
- application of the second signal, derived from the defect signal, to the regulating input of the filter 5 for defining the transfer characteristic of the said filter;
- application of the output signal of the filter 5 to the signal input of the regulating amplifier 6;
- application of the output signal of the regulating amplifier 6 to the electron beam detection coils 3a, 3b (Figure 2) for the purpose of correcting the reduced image quality;
- iterative calibration of the characteristic of the filter 5, in such a way that the reduction of the imaging quality is greatly reduced or essentially compensated for, by means of the following steps:
- comparison of the corrected image with the real structure of the reference object
- alteration of the transfer characteristic of the filter 5 in such a way that the corrected image approximates to the real structure of the reference object;
- storage of data for generating the determined transfer function of the filter 5 for the image mode.

In one embodiment, these data for generating the determined transfer function of the filter 5 for the image mode are stored in a memory assigned to the image processing device 2. In a further embodiment, the filter 5 is set up for storing these data. While the imaging defect is being determined, the devices for compensating for the imaging defects are switched off. The microscope 1 according to the invention is then calibrated by the method described above, that is to say the feedforward for the measurement signal of the sensor is set as a measure of the interfering quantity.

The compensation quality is measured by repeated scanning of the reference object and comparison of the image with the real structure of the reference object. By determining the compensation quality in each case and correspondingly changing the transfer function of the filter, the feedforward is iteratively changed in such a way that the imaging defects of the scanning electron microscope are minimized.

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The microscope 1 can be calibrated with regard to location- and/or time-variable imaging defects.

For this purpose, a reference object as shown in an exemplary fashion in Figure 3 is scanned on a predetermined path in the calibration mode. The imaged reference object comprises circular gold deposits which have been deposited on a substrate and are arranged in a predetermined manner. The scanning device of the microscope is driven externally, with the result that a selected section of the reference object is acquired. This path may, for example, be closed like that shown by the curve 9. Individual objects 8 are situated on this closed path, to which objects the image acquisition device 2 responds and generates a signal not equal to zero. This is shown schematically and by way of example in Figure 4, which illustrates the signal profile 10 acquired at a given instant t_i during the traversal of the closed curve 9. Time-dependent interference can cause time-dependent imaging defects. For this reason, in the illustration of Figure 4, the closed curve has been traversed four times at intervals. The resulting four signal profiles 10 are thus also a measure of the temporal dependence of the interference. Furthermore, the traversed curve is altered by varying the radius R, whereby location-dependent imaging defects can be detected. According to the invention, the time- and/or location-dependent imaging defects are determined by comparison of the

image in the image processing device 2 with the predetermined reference object, which is known exactly. In the example represented in Figure 4, the time-dependent imaging defect is illustrated by the curve 11.

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The image mode is the operating mode of the inventive scanning electron microscope 1 in which the actual sample is measured. The filter 5 transfer characteristic determined in the calibration mode is invariant during the subsequent image mode with regard to the characteristic defined in the calibration mode. As explained above, however, it can vary with respect to time and as a function of the scanning location.

Assuming an essentially constant correlation between the electromagnetic interference field and the imaging defect caused by this interfering quantity, the output signal of the filter 5, after passing through the regulating amplifier 6, is applied to the electron beam deflection unit 3, with the result that image defects are essentially compensated for even in the event of a change in the ambient influences, that is to say the strength of the electromagnetic interference field.

In an embodiment developed further, in addition to the electromagnetic interference fields, air vibrations and/or ground vibrations are also detected by corresponding sensors 4, the signals that are output pass through calibratable filters 5 which are assigned to the respective instances of interference and have adjustable transfer characteristics, and, after additional matching in the regulating amplifier 6, are applied to the deflection unit as a further control signal and/or to other actuators, with the result that the imaging defects caused by air vibrations and/or ground vibrations are also greatly reduced or essentially compensated for.

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The necessity of having to switch back and forth between different operating modes of the apparatus is overcome in the embodiment described below by virtue of the fact that the apparatus is set up for automatic calibration of the filter during the image mode. In order to simplify the explanation, this embodiment is again described with regard to a scanning electron microscope, but is not restricted thereto. The apparatus essentially comprises the components of the scanning electron microscope described above, with the exception that in the image processing device 2 the acquired image is analysed and a signal dependent on the analysis is applied as second signal to the calibration input of the filter 5. In the exemplary embodiment, this image analysis comprises the recursive determination of the displacement of the line centroids of successive image lines within the whole image. The analysis is based on the insight that images of objects in imaging and/or scanning apparatuses 1 are generally not stable with respect to time on account of the influence of the interfering quantities of the imaging. For elucidation purposes, Figure 5 illustrates the profile of the brightness within four selected image lines, the centroids of the brightness distribution in each line being identified by a circle and the curve 15 illustrating the displacement of this centroid of the chronologically successively scanned lines. In a manner corresponding to the respective line acquisition instants, the magnitude of an exemplary interfering quantity which causes the corresponding pixel displacement of the centroid within the lines is plotted as curve 14 on the left-hand side. In this way, it is possible to produce a correlation between the interfering quantity and the imaging defect caused by this interfering quantity. The pixel displacement of the line centroid from one image line to the next

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serves as the amplitude of the image interference. The line frequency permits an assignment of time and frequency for the correlation in the case of the active compensation signal application of the feedforward signal. If the external sensor as shown in Figure 1c arrow from 3 to 2 is read in in parallel with the determination of this pixel displacement at the beginning of each line, a time-parallel or simultaneous detection of the image interference and of the interfering influence that causes this interference can be performed. In principle, assuming sufficient coherence, it is thus possible to directly calculate the transfer function to be set at the filter 5 in order to essentially compensate for the image interference. In an alternative embodiment, fundamental assumptions are made concerning the poles and zeros of the transfer function of the filter, and the individual parameters of the variably configured functions are optimized iteratively.

An exemplary method for determining the centroid displacement of successive lines is briefly outlined below. On the basis of the sampling theorem, it is possible to compensate for interference frequencies which are less than half the sampling frequency. Furthermore, the method presupposes that individual objects within the image are very much larger than the line spacing and that centroid displacements perpendicular to the scanning direction in the image are small in comparison with centroid displacements parallel to the line direction. Moreover, it is assumed that the difference in the intensity $\varepsilon_n(t)$ of neighbouring lines is small, and the intensity f_{n+1} of the line n+1 can be written as follows:

$$f_{n+1}(t) = f_n(t) + \varepsilon_n(t).$$

If this system is then interfered with, assuming that the

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interference causes a temporal displacement Δ_n of

effect on the image in the latter. In Figure 8, the filter, the amplifier and the control element are not explicitly shown but rather are contained integrally in the image processing device 21. According to the invention, then, in this apparatus a compensation signal is not applied to an actuator which influences the imaging, rather, instead of this, the image display 22 is influenced directly. The camera system comprises a CCD camera 19 with a monitor, an image frequency of 25 Hz being worked with. The image processing device 21 is set up for storing successive images. By means of image analysis, the displacement of the image centroid of successive images in two mutually orthogonal directions is calculated and used to set the transfer function of the digital filter 5 in a similar manner to that in the embodiment described above. An illustrative representation of this displacement of the centroid of successive images 16 is shown in Figures 6 and 7. The curve 17 in Figure 7 shows the profile of the coordinate x of the centroid with time. The differences between two scanning points, for example t_0 and t_1, thus correspond to the image refresh frequency.

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A further embodiment, in comparison with the embodiment described above, enables instances of interference to be corrected by the compensation signal application even at frequencies which are greater than the image refresh frequency of 25 Hz. For this purpose, the transfer function, which is defined by the points of resonance in the mechanical construction of the microscope, is implemented as the filter 5. In this way, a base vibration X generates a relative movement Δx at the microscope. The general transfer function is thus completely determined by the actual sensitivity $\Delta x/X$, the resonant frequency f_R and by the parameter Q, which defines the asymptotic decline of $\Delta x/X$ at high frequencies.

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By determining three points on the curve

below the resonant frequency f_R as well, it is thus possible to infer the entire function and use it in the feedforward control by application of a compensation signal also for interference frequencies which are greater than the image refresh frequency.

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In contrast to the embodiments described heretofore, according to the invention it is possible, moreover, to use the image information not in feedforward arrangement but in a traditional feedback arrangement for the compensation of image interference. This is illustrated schematically in the block diagram of Figure 1d. The sensor whose signal is fed forwards is omitted, and instead of this the centroid displacements determined in the x- and/or y- axis from the image analysis are fed back into a suitable control element, in this case a device for displacing the sample, after passing through an adjustable transfer function.

In further embodiments (not illustrated in any detail here) of the invention, the apparatus may be a force microscope, a surface roughness measuring instrument, an optical scanning microscope or a lithography installation.

Depending on the embodiment, in the case of electron microscopes, the driven actuators and control elements comprise the already described electron beam deflection devices and/or control elements in the image processing device, and in the case of optically operating apparatuses, the actuators comprise, depending on the embodiment, devices for deflecting the light and/or devices for deflecting the sample and/or control elements in the image processing device. A control element in the image processing device in this case designates, by way of example, the influence on a parameter which has effects on the calculation of the image. Moreover, use is made of further actuators which are sensitive to vibrations, and also force actuators